and marls occur between the gypsums. The opportunities for examination in the Holston region are so limited that one cannot determine whether or not any such variations in activity of the springs occurred there.

NOTE.—The map accompanying this memoir is based on the old State map as used by Mr. Boyd in his Resources of Southwest Virginia, but the scale has been changed and a number of alterations have been made. It is still very inaccurate, but no better map is in existence. I have to acknowledge the courtesy of Maj. Powell, Director of the U. S. Geological Survey, and of Mr. Gannett, Chief Topographer of the Survey, in supplying photographic copies of the unfinished maps of the region. These have afforded real aid in working out the geology at localities where the other map had led me into serious error.

Some Notes Respecting Metamorphism. By John J. Stevenson, Professor of Geology in the University of the City of New York.

(*Read before the American Philosophical Society, December 7, 1884.*)

I have gathered together in this paper a number of notes made from time to time respecting the effect of certain agencies, which are regarded usually as especially active in inducing metamorphism of rocks.

Effect of proximity of Metamorphosed Rocks.

The following section was obtained on Four-mile creek, a stream entering South Park, Colorado, from the west; the rocks are Siluro-Cambrian:

1. Limestone, much altered.
2. Conglomerate and quartzite, imperfectly exposed.
3. Concealed, with occasional outcroppings of quartzite.
4. Quartzite.
5. Limestone, arenaceous, somewhat changed.
6. Sandstone, unchanged, light gray.
7. Sandstone, unchanged, shaly partings, dark gray.
8. Sandstone, slightly changed with layers of unchanged shale.
9. Sandstone, somewhat changed, very micaceous, dark.
10. Quartzite, mostly white, lines of cleavage distinct.
11. Granite and gneiss.

The total thickness of section is not far from 350 feet. A structureless quartzite rests on the Archæan, but above that the degree of change di-

minishes to the top of No. 6, that and the underlying stratum being wholly unchanged, so far as the eye could determine; above these the change is distinct, for Nos. 2, 3 and 4, are perfect quartzites so far as they are exposed. The agent which can convert sandstone into structureless quartzite does not suffice to effect much change in limestone, for the limestones of the section are rendered merely brittle, there being no trace of crystalline structure.

Rocks of the same age at the head of West Fork of Taylor river, also in central Colorado, show a somewhat similar condition:

1. Quartzite, black.
2. Quartzite.
3. Shales, somewhat arenaceous and almost unchanged.
4. Quartzite, structureless.
5. Sandstone, little changed.
6. Quartzite, on top completely changed; middle, the change is slight; but at base the quartzite is structureless.
7. Granite.

The total thickness of section is not far from 250 feet. The conditions are more marked here than in the previous section, for in No. 6, which appears to be a continuous mass, the change is least in the middle. No. 5 is a thick stratum lying between thicker ones, which have been wholly changed, yet it seems to be wholly unchanged.

The unchanged rocks in each section are more or less argillaceous.

The Cretaceous rocks in South Park, Colorado, show some interesting differences, though the conditions appear to be precisely the same. On the west side, where the South fork of the Platte river breaks through a low ridge, the sandstone and conglomerate of the Dakota rest on gneiss and show no evidences whatever of having been subjected to any metamorphosing agent; on the east side near the Sulphur Springs, the same beds are found in the same relative position, but entirely changed, the conglomerate being converted into remarkably beautiful quartzite. The Colorado limestone on this side has been changed in color and it breaks along well defined planes. The Dakota beds are shown west from the main divide at the junction of Taylor and East rivers, where they are resting on gneiss and are wholly unchanged.

The Carboniferous rocks rest directly against the Archæan at the head waters of the Purgatory river in Southern Colorado, but no evidence of metamorphism appears there, which is perceptible to the unaided eye. So also on Cebolla creek, a tributary to Mora river in New Mexico, limestone of Carboniferous age is seen resting on granite and wholly unchanged; but on Manuelitos creek, only a few miles away, the following section is shown:

1. Sandstone and shale, wholly unchanged.
2. Sandstone becoming quartzite below and passing imperceptibly into

3. Silicious limestone, which can hardly be distinguished from quartzite by mere optical examination.
4. Concealed, 25 feet.
5. Gneiss.

The total of the section to the gneiss is about 140 feet. The same section is exposed by a fault at not more than a mile further down the stream, but no traces of change appear.

Effect of Pressure during Plication.

The stratigraphical disturbance in the vicinity of Rock creek, a stream flowing amid the Elk range of central Colorado, is extraordinary. The structure was worked out by Mr. Holmes of the U. S. Geological Survey, whose discussion of the matter is one of the best relating to complicated stratigraphy.

In 1873, the writer made a section across this strange fault-fold.

Beginning at the mountain top on the east side of the valley and descending towards the stream, fifteen strata of sandstone and limestone were found, all wholly unchanged ; the sixteenth in the series is a slightly altered sandstone, while the seventeenth and eighteenth are thick sandstones, for the most part unchanged, but embracing thin layers of quartzite. Below these are the Cretaceous shales, in the middle of the fold, along the synclinal, but wholly unchanged.

Beyond the stream the rocks are all changed to some degree and the succession is :

1. Quartzite, structureless.
2. Quartzite, imperfect.
3. Silicious limestone, unchanged.
4. Quartzite.
5. Concealed.
6. Quartzite.
7. Shale unchanged.
8. Gypsum, anhydrite.
9. Limestone, shaly, unchanged.
10. Quartzite.
11. Gypsum, anhydrite.
12. Sandstone, somewhat changed.
13. Sandstone, much more changed than the last.
14. Gypsum, anhydrite.
15. Quartzite, showing no trace of lamination.
16. White quartzite.
17. Quartzites alternating with thin limestones; former wholly changed ; the latter almost unaffected.
18. Limestone, wholly unchanged
19. Quartzite wholly changed.

There are no great dikes here, nor are the beds very near the Archæan

rocks. The length of the section as given is not far from 1100 feet. The extent of change increases with the distance from the median line of the fold.

A fact observed here is very worthy of note. One of the conglomerate sandstones of the section contains fragments of Quartzite sometimes resembling the Silurian quartzites seen elsewhere, but oftener resembling the Carboniferous quartzites of the vicinity. The age of the fragments is unimportant in this connection; it suffices to know that the metamorphosis had taken place before the conglomerate in which they occur was formed. On Eagle river, not many miles eastward from Rock creek, the Carboniferous conglomerate contains fragments of Silurian quartzites and the unchanged Carboniferous rocks rest on the wholly changed Silurian beds. It appears hardly probable that anything connected with disturbance or folding of the rocks caused the metamorphosis of the earlier beds, for there certainly was no upheaval or serious disturbance between the close of the Silurian and the Carboniferous, as the two series are conformable, though the succession is far from being complete.

The Dakota sandstones are almost wholly metamorphosed into quartzites along the Conejos trail, which crosses the San Juan mountains from Tierra Amarilla in New Mexico to Conejos in Colorado. The most of it is a structureless quartzite. Along the same trail, the Triassic beds are metamorphosed.

The Dakota sandstone is quartzite on the easterly slope of the Sangre de Cristo mountains in Southern Colorado.

But in many instances the severest twisting and plication appear to have been without any influence whatever. The Dakota is turned on edge and often faulted for a long distance along the easterly foot of the Culebra range of mountains in Southern Colorado and Northern New Mexico, but it shows no change anywhere except where, for a little distance, it has been affected by the proximity of a dike.

The Middle Appalachian region affords many instances in which shales and sandstones have been subjected to enormous pressure and distortion without any apparent effect.

Along Clinch river in Russell county of Virginia, in the vicinity of the Clinch fault, the shales of the Knox group are twisted as badly as mica schists are in many localities, yet they show no signs of metamorphism and have not even new planes of cleavage. The Lower or Red Medina on Clinch mountain in the same county is thrown into close wrinkles which affect even the harder beds, yet no approach to change is manifest to the eye. Within the same region in Pennsylvania, the conditions are similar. In Bedford county, of Pennsylvania, the Red Medina is thrown into extremely close folds for a distance of more than 1000 feet along the easterly side of Evitts mountain, but no change appears in the rock. At a little way further east are the shales of the Hudson and Utica standing on edge but not showing slaty cleavage. There is, however, a change in the Utica, the black shales, which is noticeable here as well as further east

on the easterly side of Tuscarora mountain in Franklin county of Pennsylvania. During the folding, the rock yielded and was broken into great masses which moved on themselves so as to permit the folds to be made. These planes of fractures are the "dry seams" of the tunnel-men.

This condition is equally well marked in the great sandstones of the region. No traces of it appear on the surface, aside from the presence of occasional planes along which silicious matter appears to have been deposited and which have a slickensided surface. But in the great tunnels now driving by the South Penn. Railroad Company, the true condition is sufficiently clear. The crush broke the sandstones into enormous wedges; during the folding these were rubbed against each other so as to polish the faces and to fill the crevices with clay. These are a source of danger and anxiety to those driving the tunnels and they render arching necessary where the rock is such that arching would be thought wholly unnecessary.

The fracturing in the Utica shales is even more noticeable, for there the masses are much smaller and the fragments which fall from a tunnel roof, even when the beds are standing at ninety degrees, vary from five to five hundred pounds weight, while the slates show the results of the terrible pressure by their slickensided surfaces, separated by not more than an inch. Yet despite this terrible pressure, the black shales of the Utica appear to have lost none of their carbonaceous matter and, on the freshly fractured surface, do not differ from shales of the same age in Central New York where the disturbance has been practically nothing whatever.

The sandstones of the Vespertine and Upper or White Medina, in like manner, show no change whatever. The White Medina in its upper portion resembles quartzite, but this is due to conditions during its deposit.

Effect of Contact or Proximity of Eruptive Rocks.

The influence of eruptive rocks is as variable as that of the other agencies. Near the head of East river in Colorado, not far from the head of Rock creek, a narrow dike of trachyte cuts the Colorado shales, and they have been changed into true slate for many feet on each side. At other localities on the same stream, enormous trachytic overflows, nearly two thousand feet thick, rest on the shales. Metamorphism extends to a distance of only a few inches. Nor indeed do the shales show any change as the results of the enormous pressure of the overlying trachyte.

Dikes are very numerous in the San Juan region of Southwest Colorado.

The eruptive rocks appear to equal the sedimentary rocks in quantity. The effect on the latter is very marked, for in many places the metamorphosis is so great that one has difficulty in determining that he is not examining an eruptive rock.

In the vicinity of Old Baldy, a trachytic mass just north from Cimarron creek in New Mexico, there are many dikes which reach far out toward the east, invading the whole of the Cretaceous from the Dakota to the Laramie. There, Colorado shales have been changed into true slates;

the purer sandstones into quartzite and the micaceous sandstones, thus altered, so resemble granite that one examining only a hand specimen might well hesitate before deciding the name of the rock. The miners in the region stoutly maintain that this is granite.

Intruded sheets of basalt have converted coal into coke in Purgatory, Dillon and Upper Canadian cañons in the Trinidad coal field of Colorado and New Mexico. On the northerly slope of the Placer mountains in New Mexico, an enormous dike of trachyte has converted a bed of coal into anthracite for a distance of certainly one-fourth of a mile.

But in many cases the effect is imperceptible. Along the Upper Arkansas in central Colorado, especially in its great cañon passing through the east side of the Sangre de Cristo mountains, known further north as the Park range, numerous instances of contact between eruptive and sedimentary rocks were observed. The Carboniferous rocks dip very sharply near Pleasant valley and an overflow of basalt rests on their upturned edges. There seems to be no alteration at the line of contact. At a little way further up the river, an enormous dike breaks through the same sandstones and overflows broadly; the line of contact is well-shown on each side. Careful examination disclosed no perceptible alteration in the sandstones. At several localities within this cañon, the great sheet of lava, which extends from the eruptive area at the south-west almost continuously into South Park, is frequently seen following the eroded surfaces of the sandstones and coming down almost to the level of the road. Many opportunities occur for examination of the contact, but one rarely finds the alteration extending to more than a very few inches. These rocks are micaceous and contain a large proportion of argillaceous matter.

On Mount Lincoln, near South Park in Central Colorado, a great dike can be seen for nearly 2500 feet above the timber line, passing directly through the Silurian and Carboniferous beds. The effect on the Silurian cannot be determined as some other agent has metamorphosed those beds throughout. The change in the Carboniferous is insignificant. The limestone is altered slightly in color and is somewhat brittle, while the sandstone has become an imperfect quartzite. In each the change is perceptible for a very few feet.

In Dillons cañon, New Mexico, a sheet of basalt is shown between sandstones at a mile from the cañon's mouth. No effect whatever has been produced on the character of the rock, though vapor holes are present, showing the intense heat; yet at a short distance further up the cañon the same sheet has converted into fine quartzite the sandstone on which it rests.

In the Upper Canadian cañon a sheet of basalt has converted a coal bed into coke, but another at a few feet higher up the hill has had no influence whatever on the rock in contact with it.

On the northerly slope of the Placer mountains a narrow dike of basalt cuts through the Laramie beds, its course being fully exposed for 38 feet, including two thin beds of coal. No effect whatever has been produced on the coal even at the line of contact.